

DEVELOPMENT OF THE EARTH'S EARLY CRUST: IMPLICATIONS FROM THE BEARTOOTH MOUNTAINS

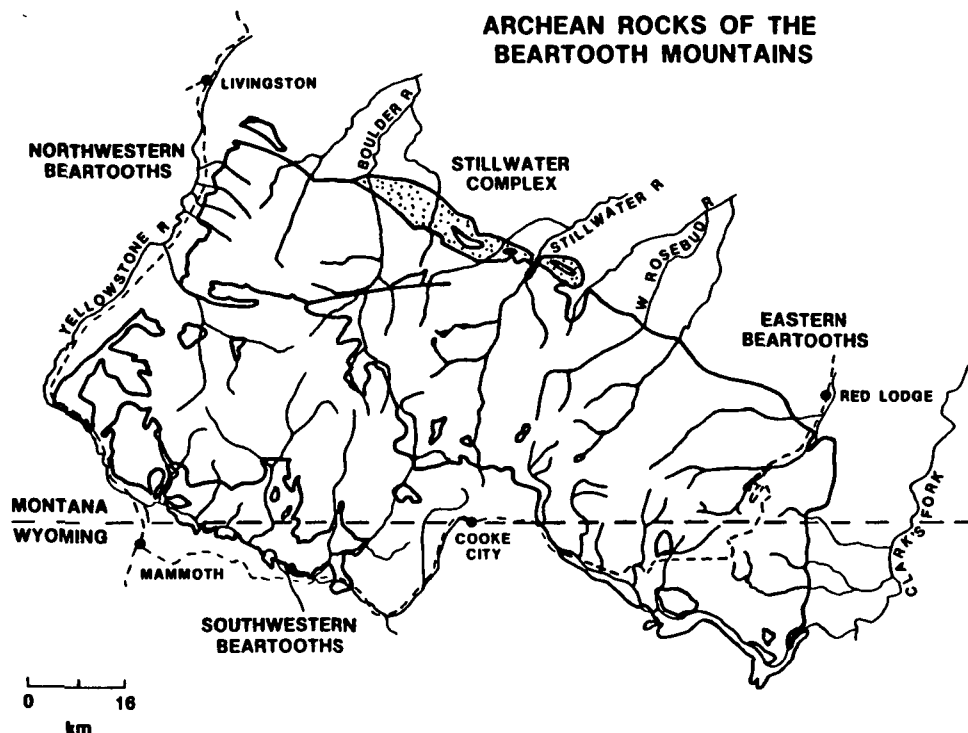
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INTRODUCTION. The Beartooth Mountains of Montana and Wyoming are one of several major uplifts of Precambrian rocks in the northwestern portion of the Wyoming Province. The range is composed of a wide variety of rock types which record a complex geologic history that extends from early(>3400 Ma) to late(~700 Ma) Precambrian time. The Archean geology of the range is complex and many areas remain unstudied in detail. In this discussion we will focus on two areas for which we have accumulated considerable structural, geochemical and petrologic information. The easternmost portion of the range(EBT) and the northwesternmost portion, the North Snowy Block(NSB), contain rather extensive records of both early and late Archean geologic activity. These data are used to constrain a petrologic-tectonic model for the development of continental crust in this area.

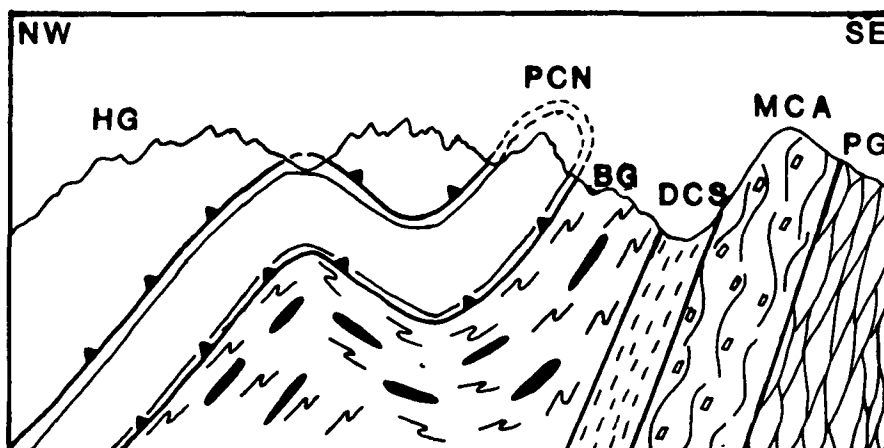


GEOLOGIC FRAMEWORK. Early Archean The oldest rocks identified in the EBT are supracrustal rocks that include metamorphosed basalts, silicic volcanics, ultramafics, ironstones, and various clastic sedimentary rocks(pelites, wackes, and quartzites)[1]. These rocks are found as meter- to several kilometer-sized inclusions in younger granitoids. The contacts between the different supracrustal rock types are usually tectonic and little original stratigraphy is discernible. Major, trace and REE analyses of these supracrustal rocks reveal several interesting features: 1) The earliest basaltic rocks differ from later ones in the EBT by having generally low REE abundances(10-20x) with relatively flat patterns; some komatiitic compositions may be present. 2) Rocks whose protoliths were intermediate to silicic volcanics are relatively abundant; those having dacitic to rhyodacitic compositions have REE patterns

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much flatter than later intrusive rocks of similar bulk compositions. 3) Clastic rocks typically show notably high Cr and Ni abundances, especially in the quartzites[2]. Larger enclaves of these supracrustal rocks record a granulite grade metamorphic event(800°C, 6 kb) while smaller enclaves and xenoliths are more likely to record a later amphibolite grade metamorphic event. Rb-Sr and Sm-Nd whole rock data for a variety of supracrustal rock types suggest that the time of granulite grade metamorphism was 3400 Ma ago[3].

Early Archean rocks from the NSB are concentrated in a single structural unit, the basement gneiss(BG of the cross section)[4]. This unit constitutes a ductile shear zone that formed at relatively low temperature(~500°C). Compositionally, the unit is typically trondhjemitic with amphibolitic layers conformable to the shear foliation. Rb-Sr and Sm-Nd studies indicate that the silicic portion of the gneiss is ~3500 Ma old. The relationship of the age of shearing to the age of formation of the protolith is unresolved. Other early Archean rocks are found in the heterogeneous gneiss(HG) unit of the cross section. This unit is a complex mixture of supracrustal lithologies and tonalitic to granitic gneisses. The tonalitic portions appear to be chronologically equivalent to the basement gneiss.



Cross section of the North Snowy Block. The lithologic units are the Heterogeneous Gneiss(HG), the Pine Creek Nappe(PCN), the Basement Gneiss(BG), the Davis Creek Schist(DCS), the Mount Cowan Augen Gneiss(MCA), and the Paragneiss(PG).

Late Archean The EBT was the locus of major magmatic and metamorphic activity during the period 3000-2800 Ma ago. This episode of intense activity began with the eruption and shallow level emplacement of substantial volumes of andesitic magmas, many of which are unusually enriched in incompatible elements[5]. Subsequently, these rocks were subjected to amphibolite grade metamorphic conditions about 2850 Ma ago[1]. During the latter stages of this metamorphic event small volumes of incompatible element-rich granodiorites and much larger volumes of more normal tonalitic to granitic melts were introduced[6]. Diabase dikes were intruded immediately after the emplacement of the granitoids and dike intrusion continued intermittently until ~700 Ma.

The NSB experienced a very different late Archean history. The main lithologic associations of the NSB, except for the MCA, are in tectonic contact with one another and these contacts mark discontinuities in metamorphic grade and structural style. It appears that four of these units(PG, BG, DCS and MCA) came into their present positions prior to the emplacement of the nappe units(PCN and HG). The PCN nappe complex contains an amphibolite grade assemblage of mafic amphibolite, schist, quartzite and marble. Limited Sm-Nd data

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suggest the amphibolite originally crystallized ~3000 Ma ago. Magmatic activity is represented by the Mt Cowan gneiss(MCA) which is now a K-spar augen gneiss that was apparently intruded close to its present position. Other than the MCA, none of the other lithologic packages can be demonstrated to be autochthonous.

GEOLOGIC-TECTONIC MODEL. Any reconstruction of the sequence of events that led to the development of the current ~45 km thick continental crust in this portion of the Wyoming Province must rely heavily on data from the Beartooth Mountains. Geochemical and geochronologic information for terrains to the west is not abundant; particularly with regard to the nature and distribution of early Archean rocks. The following model, therefore, accommodates the data from the Beartooths and is compatible with the limited information available for the surrounding terrains. A proposed scenario is depicted in a sequence of cartoons at the end of this section.

The Early Archean At 3400 Ma the EBT was already a well developed continental terrain with ultramafic to silicic components that were the source for the wide variety of supracrustal rock types subjected to granulite grade metamorphism. The environment of deposition was most likely a subsiding shelf bordering a continental mass (Beartoothia?) of unknown size and thickness. That these shelf sediments were subjected to granulite grade conditions and experienced recumbent isoclinal folding suggests tectonic burial of Beartoothia by collision with another continental mass. It appears that this other continent lay to the west and was at least 20 km thick. Assuming that continental masses in this area were of comparable thickness, it seems likely that pre-collision Beartoothia was at least 20 km thick and that by 3400 Ma was roughly 40 km thick with a metamorphic geotherm comparable to modern orogenic areas (i.e. ~40°C/km). Because of the lack of variety in early Archean rocks in the NSB, they offer little additional insight into the picture developed from the EBT data except to demonstrate the relatively widespread nature of the ~3400 Ma crustal component.

Late Archean The more abundant late Archean rocks in both the EBT and NSB clearly point to differences in the tectonic regimes of the two areas. The EBT was relatively quiet from 3400 Ma until roughly 3000 Ma when large volumes of intermediate magmas were generated[6]. This occurrence is distinctive because large volumes of rocks of intermediate composition are rarely found outside of greenstone belts. Their presence here is ascribed to subduction tectonics associated with closure of an ocean basin that lay to the west. The rocks were then subjected to amphibolite grade conditions ~2850 Ma ago[1] and subsequently intruded by a suite of late synkinematic to post-kinematic granitoids(2800 Ma)[6]. Pressure estimates based upon the compositions of diabase dikes that were intruded immediately after the emplacement of the granitoids suggest crystallization at ~5 kb[8]. This magmatic episode apparently represents the end point of a major crust forming cycle as essentially no further diastrophic activity occurred in this area until Laramide time when the block was uplifted.

The late Archean history of the NSB also appears to have begun 3000 Ma ago with the extrusion of the mafic rocks of the PCN unit. Other members of this unit(quartzites, schists and marbles) suggest that the sequence was laid down on a continental margin or extensional basin underlain by continental crust. The metasedimentary nature of rocks to the west of the NSB suggests a continental margin may be more likely[10]. Compression of this area was probably concomitant with the magmatic and metamorphic activity in the EBT and terminated with the emplacement of the major thrust sheets(PCN+HGN). The allochthonous nature of many of the major lithologic packages in the NSB is reminiscent of modern accreted terrains and it is possible that major strike-slip faults were generated along this continental margin during late Archean time. Such fault systems could have moved crustal masses from the west into their

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present positions. The NSB, therefore, may mark the eastern limit of an Archean analog of a modern Cordilleran margin.

IMPLICATIONS. It is clear from the foregoing discussion that two very different types of late Archean terrains are present in the NSB and EBT regions of the Beartooth Mountains. Moreover, a review of the regional Archean geology shows that the Beartooth Mountains may lie astride a fundamental crustal boundary in the Wyoming Province. The NSB and terrains generally to the north and west are composed primarily of metasedimentary rocks with major thrust and strike-slip faulting[9,10,11]. The EBT and terrains generally to the south and east are dominated by late Archean magmatic rocks[9]. Our present interpretation suggests that this boundary was an Archean continental margin similar to modern complex continental margins that have experienced the accretion of allochthonous terrains and calc-alkaline magmatism in close proximity (e.g. the late Phanerozoic of the northwestern United States). If this interpretation is correct, the accreted nature of the Archean continental base of North America west of the Beartooths is an unevaluated aspect of the complex late Phanerozoic geologic history of the region.

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Tectonic Model for Archean Crustal Evolution in SW Montana

